The products of the action of chromic acid on sycocerylic alcohol, were a white crystalline neutral substance and a body crystallizing in large flat prisms. The latter appears to be the sycocerylic aldehyde.

II. "Analytical and Synthetical Attempts to ascertain the cause of the differences of Electric Conductivity discovered in Wires of nearly pure Copper." By Professor WILLIAM THOMSON, F.R.S. Received December 22, 1859.

Five specimens of copper wire No. 22 gauge, out of a large number which had been put into my hands by the Gutta Percha Company to be tested for electric conductivity, were chosen as having their conductivities in proportion to the following widely different numbers, 42, 71·3, 84·7, 86·4, and 102; and were subjected to a most careful chemical analysis by Professor Hofmann, who at my request kindly undertook and carried out what proved to be a most troublesome investigation. The following report contains a statement of the results at which he arrived:—

"Royal College of Chemistry,
March 10th, 1858.

"SIR,—I now beg to communicate to you the results obtained in the analysis of the several varieties of copper wire intended for the use of the Transatlantic Telegraph Company, which you forwarded to me for examination.

"I have limited the inquiry to a *minute qualitative* analysis of the wires, to a very accurate determination of the amount of copper, and an approximative determination of the amount of oxygen. The qualitative analysis has been repeated several times with as considerable quantities as the amount of material at my disposal permitted. The *quantitative* determinations of the copper have been made with particular care, and after a lengthened scrupulous inquiry into the limit of accuracy of which the method employed is capable, I am convinced that the true per-centages of copper cannot be more than 0·1 per cent. either above or below the means of the determinations, the details of which I give you in the Appendix.

"The following Table contains the results furnished by analysis:—

Conductivity of the wire, in relative measure*.	42.	71·3.	84·7.	86·4.	102.
Qualitative analysis	Copper. Iron. Nickel. Arsenic. Oxygen.	Copper. Iron. Nickel. Oxygen.	Copper. Iron. Nickel (doubtful). Oxygen.	Copper. Iron. Nickel (doubtful). Oxygen.	Copper. Iron. Oxygen.
Per-centage of copper	98·76	99·20	99·53	99·57	99·90
Amount of impurities.	1·24	0·80	0·47	0·43	0·10
	100·00	100·00	100·00	100·00	100·00

"Since it appeared probable that the extraordinary difference in the conductivity of the several specimens was due rather to non-metallic impurities than to metallic admixtures, careful experiments were made in every case for the detection of sulphur. In none of the specimens was it possible to discover the slightest trace of sulphur. Qualitative experiments having established on the other hand the presence of oxygen, probably in the form of suboxide of copper in every one of the specimens, an attempt was made to ascertain the quantities by determining the loss which the wire after rolling suffered when heated in an atmosphere of hydrogen, and by simultaneously estimating the quantity of water formed.

"In this experiment, the details of which are given in its Appendix, the following numbers were obtained:—

Conductivity	42	71·3	84·7	86·4	102
Percentage of Oxygen	0·087	0·119	0·172	0·159	0·193

"Unfortunately the same reliance cannot be placed upon these numbers as upon the preceding ones, since the method employed involves many sources of error, and want of material precluded the possibility of repeating the experiments.

"From the preceding analysis, it is obvious that the amount of impurities in the several specimens examined is small, varying as it does between 0·10 and 1·24 per cent. The number of foreign

* I have since found $10^{-9} \times 131\frac{1}{2}$ as the factor to reduce from this to absolute measure. Thus the conductivities of the five specimens are respectively 55·2, 95·3, 111·4, 113·6, 134·1, in terms of one one thousand millionth of the British absolute unit.—W. T.

constituents also is comparatively small. I should, however, state that the analytical results which I have given do not exclude the presence of exceedingly minute quantities, even of other metals which might have been detected if larger quantities of copper could have been submitted to analysis. Some years ago, Max Duke of Leuchtenberg* examined the black precipitate formed at the anode in the electrotype process, during the decomposition of sulphate of copper by the galvanic current. In this precipitate, of which considerable quantities accumulate by the gradual solution of large quantities of copper passing through the process, he found the following constituents:—

Antimony	9·22	Iron	0·30	Oxygen	24·82
Arsenic	7·40	Nickel	2·26	Sulphur	2·46
Platinum	0·44	Cobalt	0·86	Selenium	1·27
Gold	0·98	Vanadium	0·64	Sand	1·90
Silver	4·54	Tin	33·50		
Lead	0·15	Copper	9·24		

"Of these constituents, the ten first metals were obviously derived from the copper, in which they could have been scarcely detected unless by this accumulative process. Of the remainder of the constituents, the tin in a great measure is derived from the solderings.

"The results obtained in the analysis of the copper wires which you forwarded to me, appear to establish one fact in a satisfactory manner, viz. that the diminution of conductivity observed in certain specimens of copper is due to the presence in these specimens of a certain amount of foreign matter, and not, as it has been supposed, to a peculiar change in the physical condition of the metal; for in the specimens analysed the conductive power rises in the same order as the total amount of impurities diminishes.

"I have, &c.,

(Signed) "A. W. Hofmann."

"*Professor William Thomson, F.R.S., &c.*"

It appears therefore that in the case of these four specimens, the electric conductivity is in order of purity of the copper; but yet that only extremely small admixtures of other substances are to be found even in those which have but half the conductivity of the best.

* Petersburgh Acad. Bull. vii. p. 218.

On the other hand, I have found by experimenting on artificial alloys, that comparatively large admixtures of lead, iron, silver, and zinc seem to produce sometimes improvement, sometimes little or no sensible influence, and sometimes (as in the case of zinc) an injurious effect on the conductivity of specimens of pure electrotype copper from which the alloys were made. The largeness of the proportion of other metal required to produce any considerable deterioration in comparison with that of the whole amount of impurities which Professor Hofmann's investigation demonstrates in specimens of low quality as to conductivity, is worthy of remark, and seems to indicate that this low quality must be due to other than metallic impurities.

The great difference between the conducting qualities of two specimens of electrotype copper, from which two series of alloys were separately prepared, seems also to indicate some as yet undiscovered cause, as operative in general. I am assured by Messrs. Matthey and Johnson, by whom all the alloys were prepared, that similar methods were followed and equal care bestowed to ensure purity in the two cases.

The results of my measurements of conductivity are shown in the following Tables:—

TABLE I.—Two Series, Nos. 1–10 and Nos. 1–32, of Specimens prepared by Messrs. Matthey and Johnson from pure electrotype copper, and the same alloyed with other metals, as specified.

No. of Spec.	Specification of compound.	Specific conductivity.
	SERIES I.	
1	Pure copper	138·5
2	Pure copper alloyed with ·25 per cent. silver	138·5
3	Pure copper alloyed with ·13 per cent. silver	139·5
4	Pure copper alloyed with ·25 per cent. lead	144
5	Pure copper alloyed with ·13 per cent. lead	146
6	Pure copper alloyed with ·25 per cent. tin	131
7	Pure copper alloyed with ·13 per cent. tin	133
8	Pure copper alloyed with ·80 per cent. zinc	125
9	Pure copper alloyed with ·40 per cent. zinc	120·5
10	Pure copper alloyed with 1·40 per cent. zinc	103

TABLE I.—*continued.*

No. of Spec.	Specification of compound.	Specific conductivity.
	SERIES II.	
1	997·5 copper+2·5 silver	69·8
2	998·7 copper+1·3 silver	117·7
3	997·5 copper+2·5 lead	94·5
4	998·7 copper+1·3 lead	105·8
5	997·5 copper+2·5 tin	91·6
6	998·7 copper+1·3 tin	116·9
7	999 copper+1 silver	126·7
8	999 copper+1 lead	134·2
9	999 copper+·5 lead+·5 silver	128·0
10	Equal parts of 1 and 3	89·3
11	997·5 copper+2·5 iron	129·7
12	998·7 copper+1·3 iron	113·7
13	1000 copper+2·5 protoxide of copper	122·5
14	1000 parts of 3 &+2·5 protoxide of copper (too brittle to test)	
15	1000 parts of 4 &+2·5 protoxide of copper	119·7
16	997.5 copper+2·5 zinc	108·9
17	995 copper+2·5 lead+2·5 zinc	85·1
18	995 copper+2·5 lead+2·5 iron	131.5
19	998·7 parts of 11+1·3 lead	135·0
20	997·5 parts of 11+2·5 zinc	77·6
21	998·7 parts of 11+1·3 zinc	95·2
22	997 parts of 11+1·3 lead &+1·3 zinc	117·6
23	992 copper+8 zinc	118·9
24	996 copper+4 zinc	117·0
25	986 copper+14 zinc	80.2
26	982 copper+18 zinc	102·3
27	994 copper+6 zinc	109·5
28	980 copper+20 aluminium	44·0
29	990 copper+10 aluminium	128·7
30	995 copper+5 aluminium	122·5
31	997 copper+3 aluminium	130·2
32	Pure copper, from which all the above were made	120·9

TABLE II.—First Series (10 specimens) arranged in order of conductivity.

No. of Spec.	Specification of compound.	Specific conductivity.
5	Pure copper alloyed with ·13 per cent. of lead	146
4	Pure copper alloyed with ·25 per cent. of lead	144·5
3	Pure copper alloyed with ·13 per cent. of silver	139·5
2	Pure copper alloyed with ·25 per cent. of silver	138·5
1	Pure copper	138·5
7	Pure copper alloyed with ·13 per cent. of tin	133
6	Pure copper alloyed with ·25 per cent. of tin	131
8	Pure copper alloyed with ·80 per cent. of zinc	125
9	Pure copper alloyed with ·40 per cent. of zinc	120·5
10	Pure copper alloyed with 1·40 per cent. of zinc	103

TABLE III.—Second Series (32 specimens) arranged in order of conductivity.

No. of Spec.	Specification of compound with manufacturers' description of mechanical quality of wire.	Specific conductivity.
19	998·7 of No. 11+1·3 lead: fair	135·0
8	999 copper+1 lead: fair	134·2
18	995 copper+2·5 lead+2·5 iron: very good	131·5
31	997 copper+3 aluminium: good	130·2
11	997·5 copper+2·5 iron: not very good	129·7
29	990 copper+10 aluminium: good	128·7
9	999 copper+·5 lead+·5 silver: rather better than No. 8	128·0
7	999 copper+1 silver: fair	126·7
13	1000 copper+2·5 protoxide of copper: very bad	122·5
30	995 copper+5 aluminium: very good	122·5
32	Pure copper: very good	120·9
15	1000 of No. 4+2·5 protoxide of copper: better than No. 14, but not good	119·7
23	992 copper+8 zinc: first-rate alloy	118·9
2	998·7 copper+1·3 silver: fair, but rather frangible	117·7
22	997·5 of No. 11+1·3 lead+1·3 zinc: very good indeed	117·6
24	996 copper+4 zinc: moderately good	117·0
6	998·7 copper+1·3 tin: perhaps not quite as good as No. 5	116·9
12	998·7 copper+1·3 iron: frangible	113·7
27	994 copper+6 zinc: good	109·5
16	997·5 copper+2·5 zinc: first-rate alloy	108·9
4	998·7 copper 1·3 lead: rather better than No. 4	105·8
26	982 copper, 18 zinc: very good	102·3
21	998·7 of No. 11+1·3 zinc: very fair	95·2
3	997·5 copper+2·5 lead: good, but requires care	94·5
5	997·5 copper+2·5 tin: much the same as Nos. 3 and 4	91·6
10	Equal parts of Nos. 1 and 3: bad, frangible	89·3
17	995 copper+2·5 lead+2·5 zinc: very good	85·1
25	986 copper+14 zinc: first-rate alloy	80·2
20	997·5 of No. 11+2·5 zinc: very fair	77·6
1	997·5 copper 2·5 silver: fair, but rather frangible	69·8
28	980 copper+20 aluminium: not very good	44·0
14	1000 parts of No. 3+2·5 protox. copper; almost undrawable (too brittle to test).	

The alloys numbered 14 and 15 were prepared with a view to testing the possible effect of a suboxide of copper mixed or combined with the mass. Although they do not seem worse than others of nearly the same metallic composition, it cannot be considered that they demonstrate that oxygen exercises no influence, as the portion of oxide introduced may have been reduced in the melting; and indeed it is quite possible that some accident in the melting may possibly give rise to *oxidation* to a greater or less degree, and may cause some of the irregularities and uncertainties which have been observed. On this I may remark, that although I have found that no mechanical alteration by hammering, twisting, &c. produces any considerable

effect of the conductivity of one piece of solid copper, I have not yet found whether or not specimens either good or bad retain their specific qualities after melting.

I may add, that it will be of great importance to ascertain the laws of variation of conductivity with temperature, of different specimens of nearly pure copper differing largely in conductivity. I have hitherto used standards of copper wire in all the relative determinations of conductivity which I have made for different commercial specimens and artificial alloys of copper; and before I found the very large differences of conductivity shown in this and in my preceding communication to the Royal Society (June 15, 1857), it seemed natural to suppose that the relation between specimen and standard would remain constant, or nearly constant, when the temperatures of the two are varied to the same extent. Now, however, it seems scarcely probable that this can be the case, and a rigorous experimental examination of the influence of temperature becomes necessary.

P.S. April 11, 1860.—I append the following extract from evidence which I gave on examination before the Government Committee on submarine telegraphs on the 17th December, 1859, as it bears directly on the subject of the preceding article, and shows what degree of weight may in my opinion be attached to the synthetical attempts which have been described.

(*Chairman.*) Question 2458. Soon after you became a Director of the Atlantic Telegraph Company, was your attention directed to the conductivity of copper?—Yes.

2459. You instituted a series of experiments, did not you, to determine the variation of this quality in different samples of copper?—A number of samples of copper were, at my request, put into my hands for the purpose of measuring their conductivity in consequence of my having accidentally noticed differences greater than I expected in the conducting power of one or two samples which I had had previously.

2460. Will you be good enough to state the general results at which you ultimately arrived, and your modes of experimenting?—My modes of experimenting did not differ materially from the methods which had been followed by certain other experimenters,

especially in Germany, and were in reality all based on Professor Wheatstone's invention of a beautiful method for comparing resistances, to which I have frequently referred as Professor Wheatstone's electric balance.

2461. What were the results at which you arrived?—That different specimens chosen at random from the stock supplied for manufacture differed immensely in conducting power.

2462. Although nominally the same quality of copper?—Yes, although nominally the same quality of copper. All those specimens of wire were supposed to be of the very best quality, the only copper supposed to be good being that which admitted of being drawn into wire suitably for the purpose. A good mechanical quality was necessary to prevent frequent fractures in the wire-drawing; and to understand that, I should say that hanks in unbroken lengths amounting to a large mass were always required, the worse metal being found to break before it could be drawn into a hank of a certain size. The mechanical qualities seem to have been satisfactory, but no suspicion whatever was entertained that there were also large differences in electric conducting power. W. Weber had many years before pointed out considerable differences in different specimens of copper wire which he had tested. I found differences much exceeding those, and I did not, as I expected, find any approximation to a uniform average among the different specimens tested; some specimens I found nearly double in their conducting power, compared with others, reckoned according to the weight and length, allowing for the variations of gauge. Calling the best specimen which I had in the summer of 1857, 100, I found many specimens standing at 60 in specific conductivity, many standing at 50, many standing at 80, a few above 90; and so far as I can recollect, the average of a large number of specimens that I then examined may have stood between 60 and 70, but I consider the statement of such an average to be of no value, it is so much a matter of chance. If I had received a dozen specimens of a low quality below the average, or if I had chanced to receive a dozen specimens of a higher quality, the average would have been so much the lower or the higher. I never had an opportunity of measuring the conductivity of 200 or 300 miles of submarine cable; such alone would have given me exact information as to the average for that portion of cable. I may men-

tion that a month or two later, still in the summer of 1857, I received specimens of wire which were in stock for submarine telegraphs,—for some of the Mediterranean telegraphs, I believe,—which stood as low as 43 on that scale; and, lastly, I may mention that I have since met with specimens standing 2 or 3 per cent. above the 100; and an artificial alloy, which I had prepared, stood, so far as I can estimate, as high as 111.

2463. What was that alloy?—The alloy consisted, so far as I can recollect, of copper and ·13 per cent. of lead. I have made experiments upon a series of alloys, in all about 43 or 44, and have recently repeated the examination so as to arrive at accuracy, within certain limits; and I expect, immediately, to be able to communicate to the Royal Society, for publication, the results. A few months ago I sent a provisional list of the specimens, showing the relative conductivity of those alloys, but, possibly, requiring correction as to the absolute conductivity stated. That list was communicated to Mr. Latimer Clarke, and, I believe, a copy of it was laid before the Committee.

2464. (*Professor Wheatstone.*) Were you quite certain that you employed pure copper in your experiments?—I could not be quite certain.

2465. The copper might be alloyed with other things than metals; is it not very probable that it might contain some suboxide, and that the mixing of lead afterwards with it might have reduced the suboxide, and therefore have given it a higher conducting power on that account?—That is possible. I cannot say that I am at all satisfied that the experiments which I have made point out distinctly the relation between the ascertained chemical combination and conductivity. I may mention that one of my alloys was made with a suboxide melted with the copper; but the uncertainty of the process of melting the suboxide and the uncertainty as to how much of the oxidation may have disappeared in the melting, prevented me from attributing much weight to the experiment.

2466. (*Chairman.*) What was the result with that alloy; was it a low result, or a high result?—A moderate result; not a low result.

2467. But not a high one?—A somewhat high result; but I may mention that in one series the highest conductivity was found with a mixture of lead and iron; fractions of a per cent. of lead, and

fractions of a per cent. of iron mixed with pure copper gave a higher conductivity than a nominally pure copper, with which the alloys were prepared. I must mention further, that in two series the alloys, both prepared by Messrs. Matthey and Johnson, and as I have been assured with equal care, gave results presenting considerable discrepancies; the conductivity of the pure copper in the first stood high, nearly agreeing with the 100 of my first scale, the pure copper of the second series fell considerably below that limit. On this account it appears that even pure copper, carefully prepared by the electrotype process, does not always give us results which show perfectly in point of conductivity; but to make such experiments in a satisfactory manner, it would be necessary to have a thorough chemical investigation, both synthetical and analytical, of the metals used; such a thorough investigation I have not been able to carry out, in consequence of the large expense which it would entail. I may mention that Mr. Matthiessen has gone through a series of experiments on alloys, of which the chemical composition has been ascertained with all possible accuracy, and has, I believe, arrived at highly important results relative to electrical conductivity. I have been in communication with him, and have supplied him with a specimen of one of my standards. He mentions to me that he has obtained specimens conducting better to a considerable extent than the 100 of my first scale. In that respect he has confirmed what I have myself ascertained, having myself found specimens as high as 111 on that scale. A number of alloys of definite chemical composition, prepared with great care by Mr. Calvert of Manchester, and already tested by him for thermal conductivity and for mechanical properties, have been put into my hands, in order that I may measure their electric conductivities. I hope soon to be able to obtain and publish results for this series of alloys.

III. "On a new Method of Substitution; and on the formation of Iodobenzoic, Iodotoluylic, and Iodanisic Acids." By P. Griess, Esq. Communicated by Dr. Hofmann. Received January 3, 1860.

In a previous notice* I have pointed out the existence of a new class

* Proceedings of the Royal Society, vol. ix. p. 594.